BBC RD 1994/3

Research and Development Department

MEASUREMENT OF WIDEBAND MULTIPATH PROPAGATION AT 531MHz AND 1.265 GHz:

C.P. Bell, B.Sc. (Eng), **P.J. Brightwell,** M.A.,
N.J. Misson, B.Sc., **R.F. Rudd,** B.A. (Hons.),
W.F. Williams, B.A., C.Eng., M.I.E.E.

Research and Development Department
Engineering Division
THE BRITISH BROADCASTING CORPORATION

BBC RD 1994/3

MEASUREMENTS OF WIDEBAND MULTIPATH PROPAGATION AT 531 MHz and 1.265 GHz

C.P. Bell, B.Sc. (Eng.), P.J. Brightwell, M.A., N.J. Misson, B.Sc.,
R.F. Rudd, B.A. (Hons.), and W.F. Williams, B.A., C.Eng., M.I.E.E.

Summary

Multipath propagation measurements and their analyses are described The work was carried out by the BBC over the period 1988 - 1990 as a contribution to the Eureka 147 Project, with the aim of providing statistical data required in the configuration of a Digital Audio Broadcast system.

Two different areas were chosen for the tests, one considered as representative of a generally built-up area with varying degrees of urbanisation, the other on the fringe of a relatively hilly area. In the first area two widely separated frequencies in the UHF band were used to enable estimates to be made of frequency dependence.

The results are compared with those of other similar measurement programmes in both Europe and the USA available prior to 1991. In general a somewhat lower incidence of long-delay multipath was observed in the BBC results, especially in the case of the hilly area.

Issued under the Authority of

General Manager
Research and Development Department

Research and Development Department
Engineering Division
BRITISH BROADCASTING CORPORATION

(T-34)

1994

MEASUREMENTS OF WIDEBAND MULTIPATH PROPAGATION AT 531 MHz and 1.265 GHz

C.P. Bell, B.Sc. (Eng.), P.J. Brightwell, M.A., N.J. Misson, B.Sc.,
R.F. Rudd, B.A. (Hons.), and W.F. Williams, B.A., C.Eng., M.I.E.E.

1. Introduction 1

2. Instrumentation of the Multipath Measuring Equipment 1
  2.1 The system 1
  2.2 The transmitter 2
  2.3 The transmitting antenna 2
  2.4 Receiving antennas and receiver 2
  2.5 Data storage, analysis, multipath display, and measurement procedures 3

3. Test Frequencies 7

4. Areas Chosen for Tests 7

5. Numbers of Measurements in Various Terrain Categories 7

6. Results 8

7. Comments on Results in Tables 2 - 6 8
  7.1 Comparisons between 1.265 GHz and 531 MHz in Croydon 8
  7.2 Comparison between measurements at 1.265 GHz in Croydon and South Wales ... 9

8. Comparisons with results of other Measurement Programmes 9

9. Conclusions 10

10. References 11

Appendix 12

© BBC 2004. All rights reserved. Except as provided below, no part of this document may be reproduced in any material form (including photocopying or storing it in any medium by electronic means) without the prior written permission of BBC Research & Development except in accordance with the provisions of the (UK) Copyright, Designs and Patents Act 1988.

The BBC grants permission to individuals and organisations to make copies of the entire document (including this copyright notice) for their own internal use. No copies of this document may be published, distributed or made available to third parties whether by paper, electronic or other means without the BBC's prior written permission. Where necessary, third parties should be directed to the relevant page on BBC's website at http://www.bbc.co.uk/rd/pubs/ for a copy of this document.

MEASUREMENTS OF WIDEBAND MULTIPATH PROPAGATION AT 531 MHz and 1.265 GHz

**C.P. Bell, B.Sc. (Eng.), P.J. Brightwell, M.A., N.J. Misson, B.Sc.,
R.F. Rudd, B.A. (Hons.), and W.F. Williams, B.A., C.Eng., M.I.E.E.**

1. INTRODUCTION

In recent years there has been a considerable interest in determining the statistics of multipath propagation characteristics at UHF in view of the development of new wideband transmission systems. The initial interest was stimulated by the development of new systems for the Mobile Service (particularly at frequencies around 900 MHz) and resulted in the formation of the COST 207 Project[1]. However, more recently, a corresponding Broadcast Service interest was stimulated by the concept of Digital Audio Broadcasting (DAB). In both cases, the prime concern is to determine the propagation statistics relevant for the complex and difficult environment of mobile reception.

In the case of broadcasting, it has long been known[2] that simple digital modulation systems are unsuitable for mobile reception because of intersymbol interference caused by multipath. Within the European Community, the Eureka 147 project was established in 1987 to determine, *inter alia*, specifications for the modulation and sound coding systems for DAB. Complementary studies are also being carried out within the EBU.

The propagation studies described in this Report represent part of the BBC contribution to the Eureka 147 Project over the period 1988 to 1990. In the period since the work was carried out, the modulation system to be used has been agreed. This is **C**oded **O**rthogonal **F**requency **D**ivision **M**ultiplex (COFDM)[3].

The two features of this system for which knowledge of multipath propagation characteristics are of most interest are:

i) the minimum length of the temporal guard interval to be provided between symbols to avoid intersymbol interference, and

ii) the minimum bandwidth required by the individual COFDM 'ensemble'.

Whereas the importance of (i) is reduced by introduction of the Single Frequency Network (SFN) concept (in which very long guard intervals are chosen to reduce interference from other transmitters in the network), that of (ii) remains an important factor in determining options for spectrum availability. This is especially so if such a service is to be contained within existing VHF or UHF Broadcast Bands.

The intention of this Report is to summarise the results of the data obtained and to compare this with the findings of other workers prior to 1991. It is not intended here to provide any detailed discussion on the implications for system design.

2. INSTRUMENTATION OF THE MULTIPATH MEASURING EQUIPMENT

2.1 The system

There are a number of ways by which delays in a particular environment can be assessed (e.g. conventional pulse techniques, swept frequency or correlation techniques). The method chosen is that of correlation, whereby a 10 bit pseudo-random binary sequence (PRBS) modulated carrier is transmitted and an identical PRBS in the receiver cross correlates with the received signal. This cross correlation process separates the wanted signal from the noise, leaving only the wanted carrier and any related reflections.

The correlator stage can be considered in two parts. The first phase locks a local PRBS to the dominant incoming signal. The second provides a delayed version of the sequence, and the correlation between this and the incoming signal is measured. This process is repeated many times at different offsets. The delay, which can be either positive or negative, is controlled by the microcomputer. This is also used to determine the range of delay to be measured; this delay range is called the delay window*.

The temporal resolution of the system is determined by the bit rate of the PRBS — 8 MHz was chosen. This choice was a compromise between radiated bandwidth and system resolution. With an 8 MHz bit rate, a delay resolution of 0.125 μs is attainable, enabling transmission path length differences down to 38 metres to be measured. A block diagram of the correlation system is given in Fig. 1, and the separate elements of the system are discussed below.

---

* N.B. This should not be confused with the more specialised use of this term to define the length of the middle portion of the power profile, containing a certain percentage of the total energy of the impulse response.

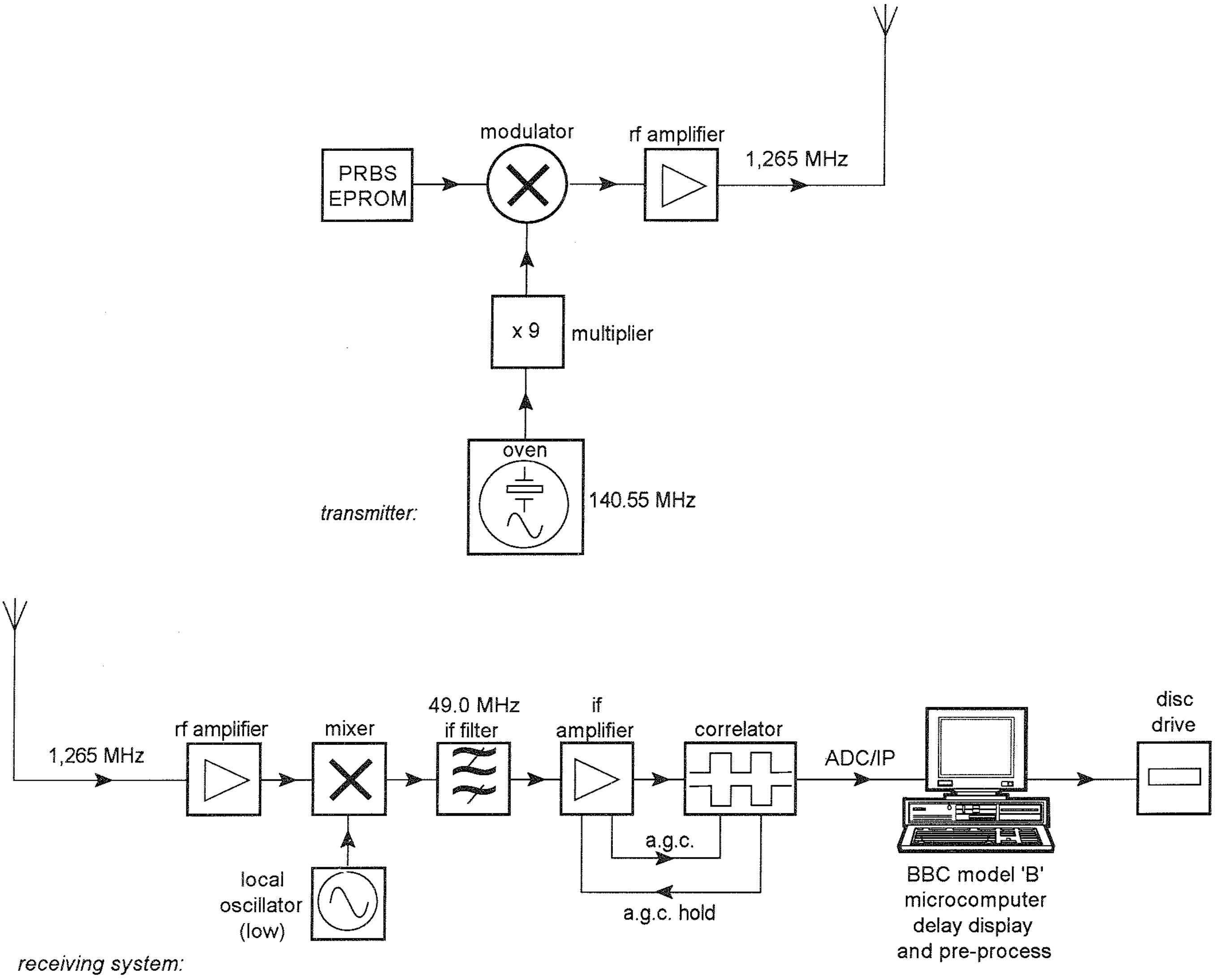

Fig. 1 - Schematic of transmitter and receiver as used for measurements at 1.265 MHz.

2.2 The transmitter

This consisted of a stable source, modulated in a balanced mixer by an 8 MHz PRBS, which was stored in an erasable programmable read only memory (EPROM). The resulting modulated signal was then amplified to a level of 10 W peak RF output. The transmitter was mounted in a ruggedised waterproof housing, enabling it to be mounted on any suitable transmitting mast platform.

The PRBS was stored in EPROM to ensure that the sequence was accurately transmitted on every occasion. It was considered that a conventional shift register code generator might have suffered impulse interference, since the transmitter was expected to function in areas of high RF fields and in an environment subject to switching impulses from machinery and lifts, etc.

The transmitter was mounted close to the transmitting antenna and connected with a short length of coaxial feeder cable.

2.3 The transmitting antenna

This antenna was circularly polarised and consisted of a pair of crossed dipoles fed in quadrature through a zero dB output ratio directional coupler. Printed circuit techniques were used with the dipoles mounted above a ground plane with boxed sides. Glass reinforced plastic (GRP) weather shielding was incorporated into the design.

2.4 Receiving antennas and receiver

A microstrip patch antenna was produced for the first test transmission frequency (1.265 GHz). This was because it was foreseen that, in addition to multipath measurements of a terrestrial transmitter, it might also have been advantageous to carry out measurements, close to the transmitter site, for simulating satellite transmissions. For more general measurements at low elevation angles, quarter-wave vertical whip antennas were used. These were mounted on the roof of the measuring vehicle.

The receiver used an intermediate frequency (IF) of 49 MHz, and the output from the IF amplifier passed through a filter of 16 MHz bandwidth. The automatic gain control was fed to the correlator and a gain hold signal was fed back to the IF stage to stabilise the gain whilst correlation took place.

2.5 Data storage, analysis, multipath display and measurement procedures

A simple 8-bit (BBC Acorn) microcomputer was used to control the correlator, to determine the width of the delay window and also to pre-process the measured data and write the information to a floppy disk, for subsequent processing at base. A facility was provided to display individual delay sweeps as a confidence factor for the fieldwork team.

The base processing analysis software was written for an Atari Mega ST2 microcomputer. An analysis of individual delay sweeps could be made, giving average delay, delay spread or correlation spectrum for each sweep or sweep average.

In absence of any timing reference between transmitter and receiver, it was, of course, not possible to explore the full complex response of the channel. In particular, it was not possible to examine Doppler effects. This being so, the vehicle speed at the time of making measurements was only critical to the extent that the propagation characteristics remained sensibly constant during the period of each individual measurement. For this reason, measurements were made with the vehicle either moving very slowly or stopped. Generally, ten or so measurements were made at about 10 m intervals, and the results then averaged.

Individual results of each set of measurements could be displayed on a three-dimensional graph, such as in Fig. 2, the resulting averaged value being given in Fig. 3. From this averaged delay profile, the first and second moments were then calculated to provide the average delay and the delay spread. A Fourier Transform of the average delay profile was used to generate the correlation spectrum.

Examples of typical average delay profiles and correlation spectra for suburban and city centre measurements are represented in Figs. 4 and 5 respectively. The presentations of correlation spectra also show the difference between the actual correlation spectrum and that obtained in an ideal case with no multipath signal. This demonstrates the manner in which the presence of reflections reduces the correlation bandwidth and hence the data handling capacity of the channel.

Even averaged delay profiles, and the derived correlation spectra can vary substantially over small distances, especially in dense urban areas. This is demonstrated in Figs. 6 and 7, which show results obtained over two sections of road only about 100 m apart.

The analysis software contained provisions for:

i) clipping the base level of the response such that noise and multipath below a given threshold does not show. This avoided the need to display and analyse signal components at levels having no practical significance;

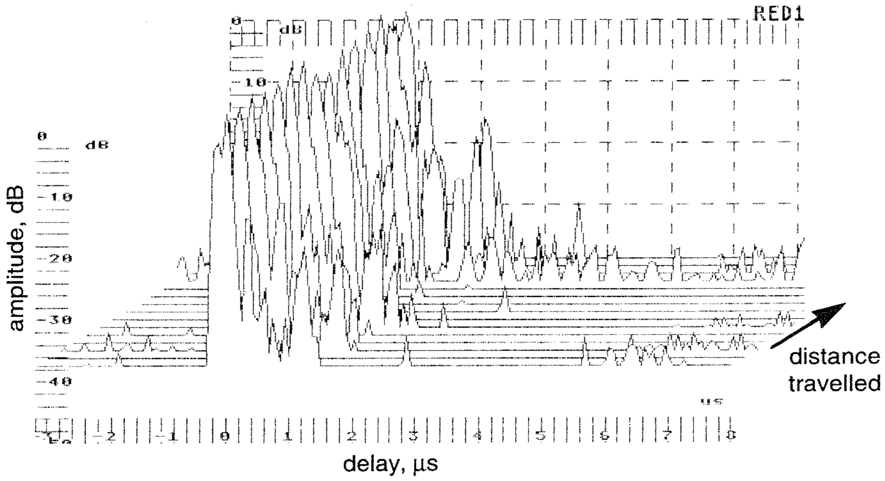

Fig. 2 - Three-dimensional plot of delay profiles.

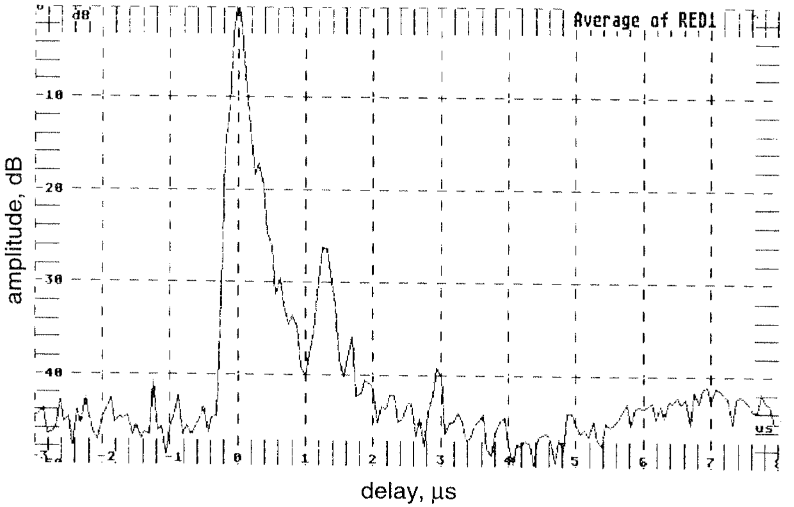

Fig. 3 - Average delay profile derived from Fig. 4 (suburban route).

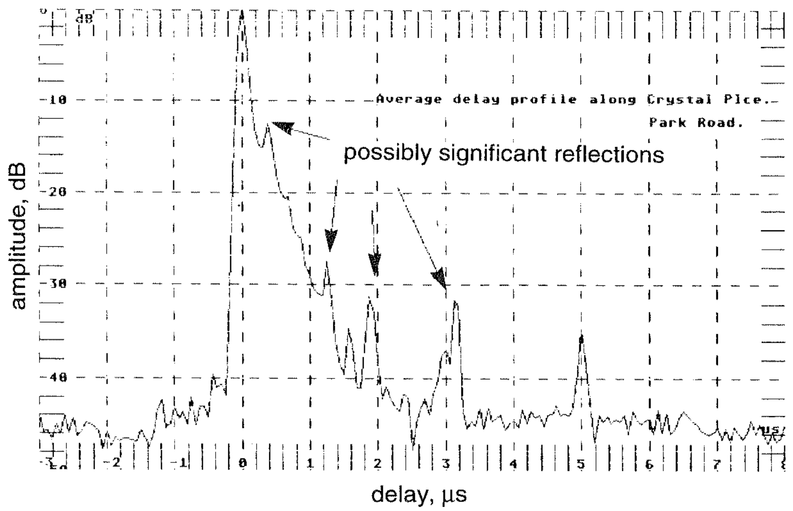

Fig. 4(a) - An average delay profile showing significant reflections (suburban with trees).

Mean delay is : 0.05772473 µs
Delay spread is : 0.2704687 µs ← along CP Park Road
1/spread = 3.697285 MHz
50% correlation bandwidth is : 3.299424 MHz
Mean delay is : 3.982487E-3 µs
Delay spread is : 0.1128083 µs ← ideal
1/spread = 8.864598 MHz
50% correlation bandwidth is : 4.546368 MHz

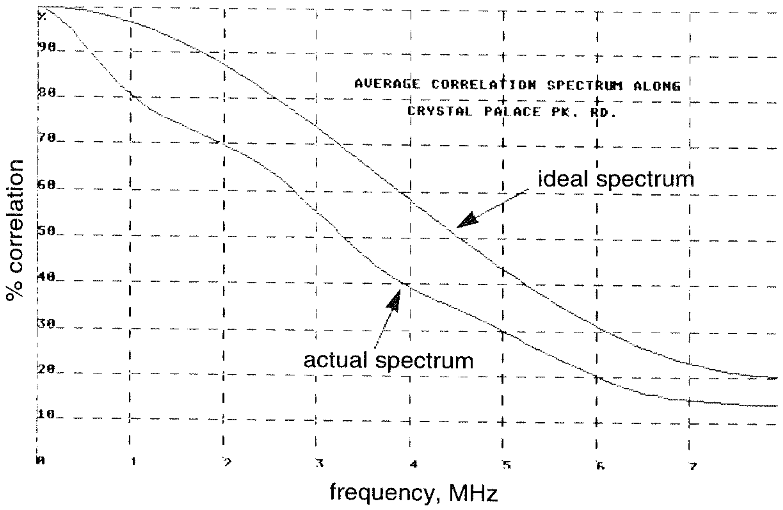

Fig. 4(b) - Correlation spectrum derived from the delay profile of Fig. 4(a) compared with an ideal spectrum.

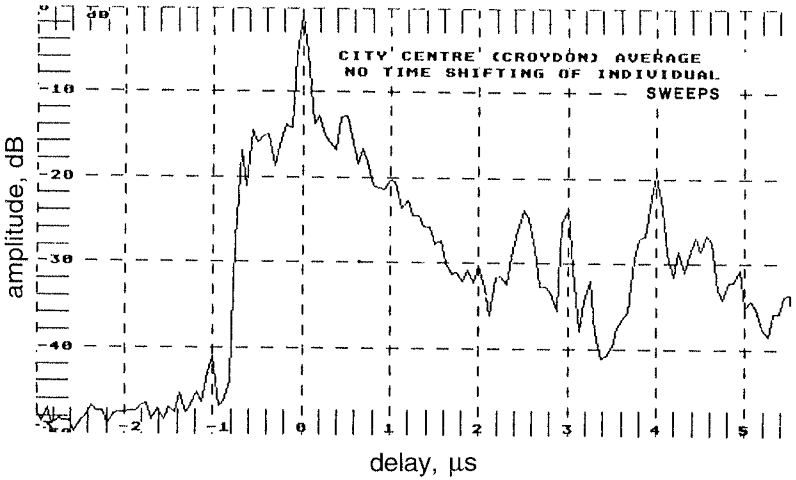

Fig. 5(a) - Average delay profile Croydon ('city centre').

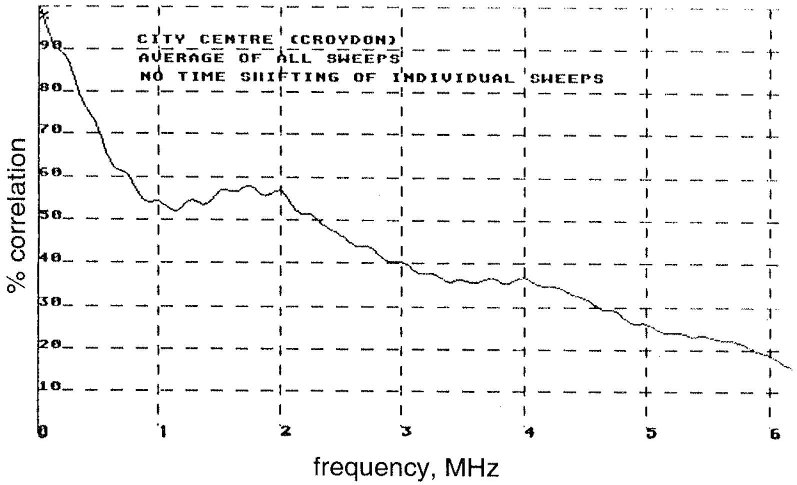

Fig. 5(b) - Correlation spectrum derived from Fig. 5(a) Croydon ('city centre').

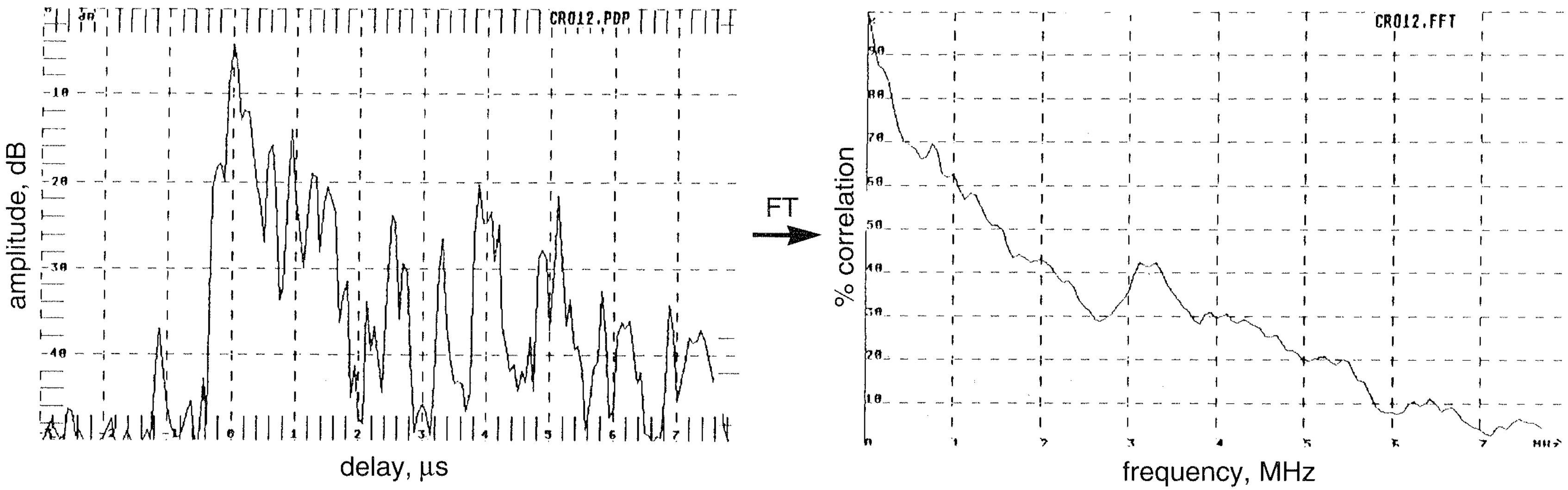

Fig. 6(a).

Fig. 6(b).

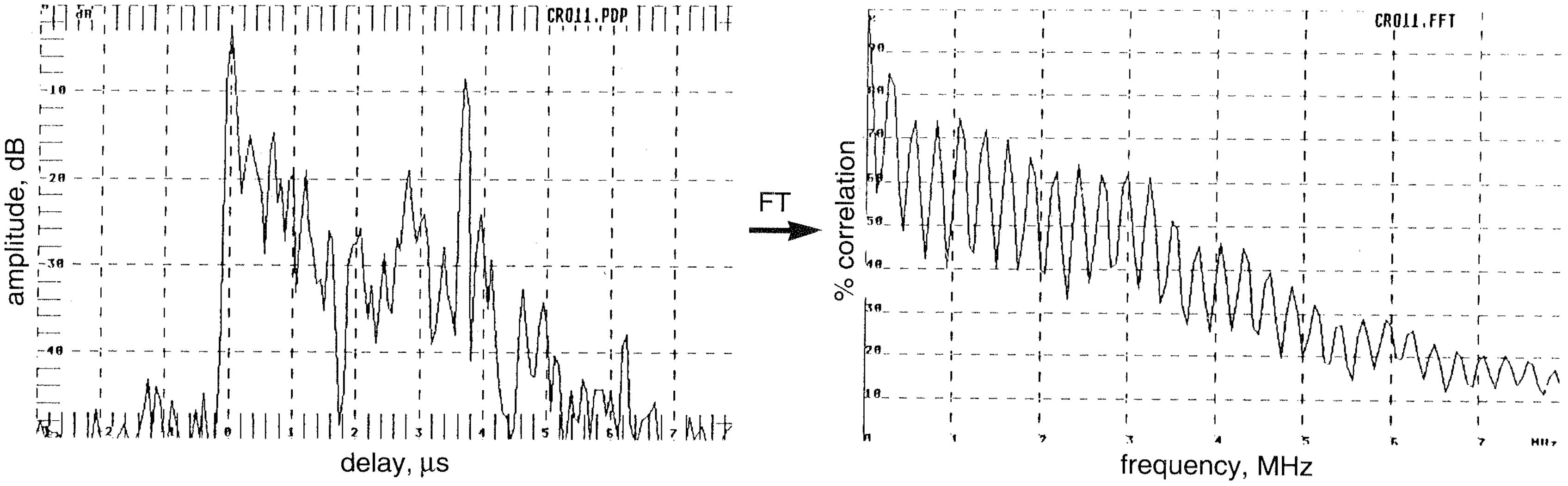

Fig. 7(a).

Fig. 7(b).

Figs. 6 and 7 - Comparison of frequency correlation functions (FCF). The two power delay profiles on the left were measured at points in a dense urban area separated by only ~100m.

ii) resetting the reference time on individual responses This facility was required because, in absence of a reference to identify the direct signal, the equipment may lock to a reflection, if this is of significantly greater amplitude;

iii) recording of signal input levels to the receiver, to enable the shadowing effects of individual obstructions to be determined. This information was derived from the receiver AGC. Although this aspect will not be discussed further in this Report, it may be of interest to note that at the first test frequency (1.265 GHz), shadow losses in excess of about 20 dB were recorded behind individual buildings.

3. TEST FREQUENCIES

The first series of tests were carried out at a centre frequency of 1.265 GHz. This is in a Band primarily allocated to the Radiolocation Service (ground radars), with secondary allocation to the Amateur (and Amateur Satellite) service. The choice of frequency was determined by a number of factors. The only one which need be mentioned here is that it is sufficiently representative of the Band (1.452 - 1.492 GHz) which has subsequently been assigned to the Broadcast Satellite Service.

Having carried out a programme of measurements on this frequency from two different transmitting sites, it was considered useful to carry out comparative measurements at one of these sites at a substantially lower frequency.

This second frequency was centred on 531 MHz (Channel 28 of UHF Television Band IV). Here, the choice was determined by expediency, this being virtually the only available channel within the UHF broadcast band at the chosen site. Even this frequency presented some quite severe filtering problems, because television Channels 26 and 30 were each being transmitted at 1 MW ERP from the same mast!

4. AREAS CHOSEN FOR TESTS

For the first test programme, the transmitter was mounted at a height of 120 m above ground at the Crystal Palace transmitting station in south London. Being sited in a densely populated area this enabled measurements to be made in a fairly wide variety of terrain ranging from the dense urban to suburban, with a limited amount of rural area, most of which was wooded to some extent. The terrain was undulating with a 'terrain irregularity factor' (as defined in CCIR Recommendation 370) of the order of 60 m. Whilst the possibility existed of significant multipath reflections from a group of high-rise office buildings in the Croydon area (some 5 km south of the transmitting site), there were no terrain features likely to give rise to long-delay reflections.

In order to investigate a more hilly area, the equipment was then taken to South Wales and mounted on the mast at the BBC Wenvoe station, near Cardiff. Although the transmitting antenna here was mounted at a slightly lower height above ground (100 m) than at Crystal Palace, the site itself was somewhat more prominent above the surrounding countryside. The local terrain was also more undulating, with a range of hills commencing some 8-10 km north of the transmitter site and having heights in excess of 300 m. The measurement area included the city of Cardiff (comprising mainly low-rise buildings), but was otherwise of a predominantly rural nature.

Both measurement programmes detailed above were carried out at 1.265 GHz. Finally, the equipment was re-built to operate at 531 MHz and re-installed at Crystal Palace.

5. NUMBERS OF MEASUREMENTS IN VARIOUS TERRAIN CATEGORIES

As described above, each 'measurement' comprises an averaged value of about ten individual delay profiles obtained over a distance of about 100 m. Each was classified into one of the following four categories: Rural, Suburban, Urban or Dense Urban. The classification was done on a subjective basis by the engineer. The total number of measurements used in subsequent analyses are indicated below in Table 1.

Note: As most of the measurements of the transmissions from Crystal Palace were carried out in and around the town of Croydon, this name is used hereafter for tests in this area.

Table 1: Numbers of measurements in individual categories.

Category	Croydon 1.265 GHz	Croydon 531 MHz	S. Wales 1.265 GHz
Rural	25	5	42
Suburban	48	72	26
Urban	18	37	6
Dense Urban	19	16	13
Total	110	130	87

The relatively larger number of rural measurements made in South Wales reflects both the nature of the terrain and the fact that attention was concentrated in areas expected to provide long delay multipath.

It was indicated in Section 2.3 that the receiving antenna was designed to permit reception at high elevation angles. This was to simulate transmissions from satellites. However, it was later found that only very limited use could be made of this facility, due to the difficult topography and inconvenience of access in the vicinity of the two transmitting sites. Consequently, short range results with high elevation angles are not included in Table 1 or in the analysis given below. Nevertheless, for completeness, one set of such results is discussed in the Appendix.

Table 2: Mean delay (μsecs) not exceeded at specified % of locations.

Category	Croydon 1.265 GHz		Croydon 531 MHz		S. Wales 1.265 GHz	
	50%	90%	50%	90%	50%	90%
Rural	0.02	0.1	0.19	0.36	0.1	0.3
Suburban	0.04	0.1	0.22	0.47	0.05	0.9
Urban	0.09	0.27	0.21	0.36	0.01	0.9
Dense Urban	0.38	0.89	0.41	0.69	0.07	0.18

Table 3: Delay spread (μsecs) not exceeded at specified % of locations.

Category	Croydon 1.265 GHz		Croydon 531 MHz		S. Wales 1.265 GHz	
	50%	90%	50%	90%	50%	90%
Rural	0.25	0.35	0.31	0.48	0.4	1.7
Suburban	0.25	0.4	0.36	0.54	0.3	1.95
Urban	0.24	0.44	0.38	0.51	0.28	0.3
Dense Urban	0.6	1.02	0.51	0.75	0.28	0.6

Table 4: 50% correlation bandwidth (MHz) not exceeded at specified % of locations.

Category	Croydon 1.265 GHz		Croydon 531 MHz		S. Wales 1.265 GHz	
	50%	90%	50%	90%	50%	90%
Rural	4.3	3.5	1.9	1.0	4.25	3.8
Suburban	3.7	2.8	1.3	0.6	3.75	0.2
Urban	2.7	0.9	1.4	0.8	3.75	2.2
Dense Urban	1.1	0.4	0.8	0.3	3.8	2.6

6. RESULTS

As already described, the averaged values of delay profiles were analysed to obtain the values of mean delay, delay spread, and correlation bandwidth. From these individual results statistical analyses were derived, as indicated in the Tables 2 - 6.

7. COMMENTS ON RESULTS IN TABLES 2 - 6

7.1 Comparisons between 1.265 GHz and 531 MHz in Croydon

Table 3 indicates that in virtually all cases the delay spread increases as the area becomes more cluttered. This is perhaps surprising as it might be expected that increasing local clutter would progressively tend to screen longer-delay reflections, and this was, indeed, found in the results of other measurements[4] in London. However, all the delay spreads found were quite small indicating that in this area no significant long-delay reflections occur.

Except for the dense urban case, the delay spread is rather less at the higher frequency.

In virtually all cases the correlation bandwidth is greater at the higher frequency and increases as the surroundings become more rural. This, of course,

Table 5: 90% correlation bandwidth (MHz) not exceeded at specified % of locations.

Category	Croydon 1.265 GHz		Croydon 531 MHz		S. Wales 1.265 GHz	
	50%	90%	50%	90%	50%	90%
Rural	1.5	0.55	0.3	0.2	1.4	0.5
Suburban	1.1	0.6	0.3	0.15	0.9	0.2
Urban	0.5	0.3	0.3	0.2	0.5	0.4
Dense Urban	0.25	0.1	0.2	0.1	0.6	0.2

Table 6: 10% correlation bandwidth (MHz) not exceeded at specified % of locations.

Category	Croydon 1.265 GHz		Croydon 531 MHz		S. Wales 1.265 GHz	
	50%	90%	50%	90%	50%	90%
Rural	>8	7.5	4.3	3.7	>8	7.7
Suburban	>8	6.8	4.2	1.5	>8	7.3
Urban	>8	5.9	4.0	3.2	>8	6.7
Dense Urban	6.6	2.0	3.9	1.4	>8	6.3

follows as being the reciprocal of the findings for delay spread.

7.2 Comparison between measurements at 1.265 GHz in Croydon and South Wales

It had been expected that long delay reflections would be found in the South Wales area, resulting in increased mean delay, and delay spreads, with consequentially smaller correlation bandwidth. However the results give little indication of this.

The only substantial difference between the results in the two areas seems to be that delay spreads are greater (and correlation bandwidths smaller) in the dense urban areas of Croydon as compared to those in Cardiff. This may be due to invalid comparisons between 'dense urban' areas, there being few, if any, areas in Cardiff containing the sort of density of tall buildings found in Croydon.

It is considered that lack of equipment sensitivity may have contributed to the observed absence of long-delay reflections, since this limited the ability to carry out measurements in conditions where the direct signal was heavily attenuated. In extreme cases where such a long-delay signal has a greater amplitude than the direct one the receiver would lock to it and the direct signal would then be lost from the record. In this context it is of interest to note that:

i) in measurements carried out by the Swiss PTT[5] an auxiliary high-gain antenna was used to provide synchronising signals for the receiver.

ii) in (unpublished) measurements carried out in Germany by other members of the Eureka 147 Project, broadcast transmitters were used to ensure higher powers and the system also made provision for synchronisation.

In both these measurements programmes long-delay multipath signals of significant amplitude were observed. It is therefore considered that the results of the tests in South Wales must be treated with caution in terms of representation of a hilly area.

8. COMPARISONS WITH RESULTS OF OTHER MEASUREMENT PROGRAMMES

As indicated earlier an extensive study of wideband multipath propagation has been carried out under the COST 207 Project at frequencies within the range 775 MHz to 1050 MHz. On the basis of this the following values of delay spread (in μsec) were considered representative:

	Hilly	Non-hilly
Rural	5.0*	2.5
Urban	1.0	0.1

* More precisely, hilly terrain other than urban.

It may be seen that, with the exception of the non-hilly urban case all these values are greater than indicated in Table 3.

In order to extend comparisons further, an examination was made of the results of other workers[4 - 11], some of which formed contributions to COST 207. This comparison is presented in Table 7 *(overleaf)*, although it should be emphasised that it is complicated by the variety of different parameters and forms of presentation of data used by the various groups.

In the case of suburban, urban and dense urban results there is a fair degree of agreement between BBC results and those of other workers. The anomalies that do exist, such as the rather small values for delay spread measured by the BBC in urban areas, might well be explained to some extent by the considerable difference between what might be described as an 'urban' area in Victorian south London or Cardiff and in downtown Manhattan. An obvious exception involving very high values of (r.m.s.) delay spread is represented by Ref. 12, which combines the results obtained in four US cities.

A more serious difference arises in the case of rural measurements. There is a great difference between the three groups of results — those of the BBC, British Telecom and the Swiss PTT.

The BBC rural measurements in south London were made in largely flat, open areas, with only one range of hills (to about 100 metres above receiver height) behind the receiver. In contrast, those of British Telecom were made in northern England, surrounded by hills up to 500 metres above the receiver, and these recorded substantially higher values of delay spread. The measurements of the Swiss PTT were made in similar terrain to those of BT but with a much greater transmitter height (circa 400 metres above the receiver compared with circa 100 metres in the case of British Telecom). As mentioned in the Swiss paper[5], it might have been expected that the greater transmitter height would have given rise to smaller values of delay spread, but the opposite appears to be true.

Table 7: BBC results compared with other data. Values not exceeded at specified % of locations.

Frequency	Mean delay		Delay spread		0.9 corr. B/W		0.5 corr. B/W		Notes	Ref.
	50%	90%	50%	90%	50%	90%	50%	90%		
Rural areas										
200 MHz	—	—	13.5	18.5	—	—	—	—	**C**	**4**
531 MHz	0.19	0.36	0.31	0.48	0.3	0.2	1.9	1.0		**BBC**
900 MHz	1.5	3.0	3.5	7.5	—	—	—	—	**A**	**9**
Croydon 1265 MHz	0.02	0.10	0.25	0.35	1.50	0.55	4.3	3.5		**BBC**
S. Wales 1265 MHz	0.1	0.3	0.4	1.7	1.4	0.5	4.25	3.8		**BBC**
Suburban areas										
200 MHz	—	—	4.3	10.0	—	—	—	—	**C**	**4**
436 MHz	0.64	1.77	0.81	1.81	2.0	0.2	0.4	0.1	**A**	**5**
531 MHz	0.22	0.47	0.36	0.54	0.3	0.15	1.3	0.6		**BBC**
880 MHz	0.22	—	0.20	—	2.5	—	0.75	—		**6**
900 MHz	0.3	0.65	0.3	0.6	1.9	0.5	0.8	0.1	**B**	**7**
910 MHz	0.15	1.9	0.24	2.05	—	—	—	—		**8**
Croydon 1265 MHz	0.04	0.10	0.25	0.40	1.1	0.6	3.7	2.8		**BBC**
S. Wales 1265 MHz	0.05	0.9	0.3	1.95	0.9	0.2	3.75	0.2		**BBC**
Urban areas										
200 MHz	—	—	1.3	3.3	—	—	—	—		**4**
436 MHz	1.97	1.51	1.45	2.59	0.3	0.5	0.15	0.05	**A**	**5**
531 MHz	0.21	0.36	0.38	0.51	0.3	0.2	1.40	0.80		**BBC**
880 MHz	1.93	—	3.59	—	0.15	—	0.05	—		**6**
900 MHz	0.35	1.0	0.5	1.25	1.4	0.1	0.25	<0.1	**B**	**7**
900 MHz			2.0	7.0					**C, D**	**11**
Croydon 1265 MHz	0.09	0.27	0.24	0.44	0.5	0.3	2.70	0.90		**BBC**
S. Wales 1265 MHz	0.01	0.9	0.28	0.3	0.5	0.4	3.75	2.2		**BBC**
Dense urban areas										
531 MHz	0.41	0.69	0.51	0.75	0.2	0.1	0.8	0.3		**BBC**
900 MHz	0.75	1.25	1.1	1.5	0.7	<0.1	0.1	<0.1	**B**	**7**
900 MHz	0.5	2.0	0.4	1.4	—	—	—	—	**A**	**9**
900 MHz	1.1	2.0	0.5	2.0	—	—	—	—		**3**
910 MHz	—	—	1.1	2.5	—	—	0.07	0.03		**10**
Croydon 1265 MHz	0.38	0.89	0.60	1.02	0.25	0.1	1.10	0.40		**BBC**
S. Wales 1265 MHz	0.07	0.18	0.28	0.6	0.6	0.2	3.8	2.6		**BBC**

A: Not true 50% and 90% CDF values, but 'typical' and 'extreme' examples.
B: Figures quoted for 0.9 corr. B/W are actually 0.8 corr. B/W values.
C: Approximate values derived from graph.
D: R.M.S. values. Probably represents both urban and dense urban.

9. CONCLUSIONS

For urban areas there seems to be reasonable agreement between the various workers, with delay spreads in the order of 0.2 to 1.5 μs (median values), and 90% of all locations giving rise to spreads less than 2.5 μs. The corresponding median correlation bandwidths (to 0.5 correlation) vary from 0.1 MHz to 3.7 MHz.

Rural areas give rise to less well defined results, and less work has been done here. It might be expected that in more hilly regions, long-term, discrete, echoes may be apparent. If of appreciable amplitude, these would give rise to an oscillatory function for the correlation bandwidth, thus reducing its value greatly. This effect is illustrated in Figs. 6 and 7. If it is found that long-term echoes are a significant effect in such areas, this will have obvious implications for the length of 'guard interval' necessary between symbols. Such long-term echoes have been observed in the BT and Swiss experiments and also in the preliminary results of measurements in the Harz mountains. The apparent absence of such long-delay reflections from

BBC results in the Wenvoe area should be treated with caution.

In rural and suburban areas, the lower frequency appears to give significantly lower correlation bandwidths. This apparent frequency dependence may be of significance if it is proposed to use a VHF band for DAB. In this respect it may be noted that a contribution to CCIR* Study Group 5 summarising work carried out in the USSR[13] indicated that backscatter from mountain slopes is 'highly frequency dependent, with a maximum in the VHF band'. The quoted results indicate highest levels in Band II.

To some extent the decision by the Eureka 147 Project to adopt COFDM as the modulation system, together with recognition that the 'Single Frequency Network' concept leads to highly efficient spectrum utilisation for large area coverages has reduced concern about the aspect of the guard interval required to avoid intersymbol interference. This is because the guard intervals for such a network have to be sufficiently long to avoid mutual interference between the individual transmitters in the network. This requirement inevitably calls for longer guard intervals than required to protect against multipath in a single coverage area.

As stated earlier, the work described here is presented in order to ensure the results are available to other workers and is not intended to form the basis for discussion on system design. However, a number of relevant propagation parameters are important to system design and are recommended to be studied further. The advent of more powerful computers and their increased memory capability means that more data collection and analysis are now possible. For example, a more comprehensive study of the statistical extremes of channel characterisation, rather than the medians discussed in this early work, is required. Also, the bandwidths at which decorrelation occur should be investigated further in order to establish the minimum bandwidth requirements for digital transmission. This form of treatment is discussed in Annex 1-6 of ITU-R Report 1203.

10. REFERENCES

1. COST 207, 1989. Digital land mobile radio communications. Final Report of the Cost-Project 207. Commission of the European Communities, Brussels.
2. EATON, J.L. and EDWARDSON, S.M., 1978. Digital sound broadcasting tests in Band I. International Broadcasting Convention 1978. IEE Conference Publication No. 166, pp. 317-320.
3. POMMIER, D. and WU, Yi., 1986. Interleaving or spectrum-spreading in digital radio intended for vehicles. *EBU Review*, No. 217, June 1986.
4. GURDENLI, E. and HUISH, P.W., 1984. Channel sounding results in London. Submission to COST 207 Digital land mobile radio communication, COST 207 TD(87)004, Ipswich, January 1984.
5. DEBRUNNER, W.E., 1986. Multipath propagation in hilly regions. Swiss PTT Report No. VD 11.1070 C, May 1986.
6. BAJWA, A.S. and PARSONS, J.D., 1982. Small-area characterisation of UHF urban and suburban mobile radio propagation. IEE Proc. Pt. F, No. 2, April 1982.
7. DEMERY, D.A. and PARSONS, J.D., 1987. Characterisation of wideband UHF mobile radio channels. IEE Colloquium Digest No. 1987/91, Leeds, October 1987.
8. MOLKDAR, D. and MATTHEWS, P.A., 1987. Wideband measurements and characterisation of the UHF mobile radio channel. Doctoral thesis, Dept. of Electrical and Electronic Engineering, University of Leeds.
9. COX, D.C., 1972. Delay doppler characteristics of multipath propagation at 910 MHz in a suburban mobile radio environment. IEEE Trans. on Ant. and Prop., **AP-20**, No. 5, September 1972.
10. HUISH, P.W. and GURDENLI, E., 1988. Radio channel measurements and predictions for future mobile radio systems. *British Telecom Technol. J.*, **6**, No. 1, January 1988,
11. COX, D.C. and LECK, R.P., 1975. Correlation bandwidth and delay spread multipath propagation statistics for 910 MHz urban mobile radio channels. IEE Trans. of Comms., **COM-23**, No. 11, November 1975.
12. RAPPAPÓRT, T.S., SEIDEL, S.Y. and SINGH, R., 1990. 900 MHz multipath propagation measurements for U.S. digital cellular radiotelephone. IEEE Trans. on Veh. Tech., **39**, No. 2, May 1990, pp. 132-139.
13. TROITSKY, V.N., 1986. Back-scatter in the VHF, UHF and SHF bands from the slopes of mountain peaks and ranges. *Elektrosviaz*, No. 7, pp. 48-51.

---

* Now ITU-Radiocommunications Sector.

APPENDIX

Preliminary Measurement of Shunt-path Propagation

As indicated in the main text, limitations of topography and access precluded much useful information being obtained on shadow losses and multipath propagation at elevation angles relevant to satellite propagation. It had been intended to mount the transmitting antenna somewhat higher on the mast at Crystal Palace to permit a more representative simulation of such elevation angles. However, due to problems with the mast power supply at a higher platform level (197 m) this test was not carried out.

Nevertheless, Figs. A.1 and A.2 indicate the shadow loss and multipath measured behind a single large building (the Sports Hall of the Crystal Palace National Recreation Centre) which is situated some 750 m from the transmitting mast. The line-of-sight elevation angle at the receiving antenna is about 12°.

In these Figures the two ends of the run are clear of the obstruction. The frequency in use at the time was 1.265 GHz.

It may be seen that the maximum shadow loss is of the order of 20 dB. Although the sweeps recorded reflections of delays up to 6 μsecs all beyond about 1 μsec were at least 20 dB below the direct signal.

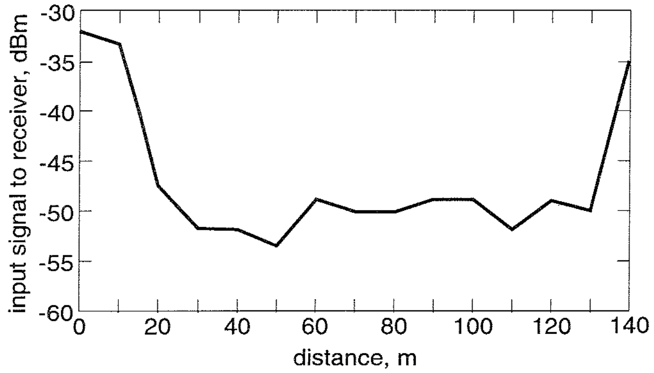

Fig. A.1 - Shadow loss (Sports Hall).

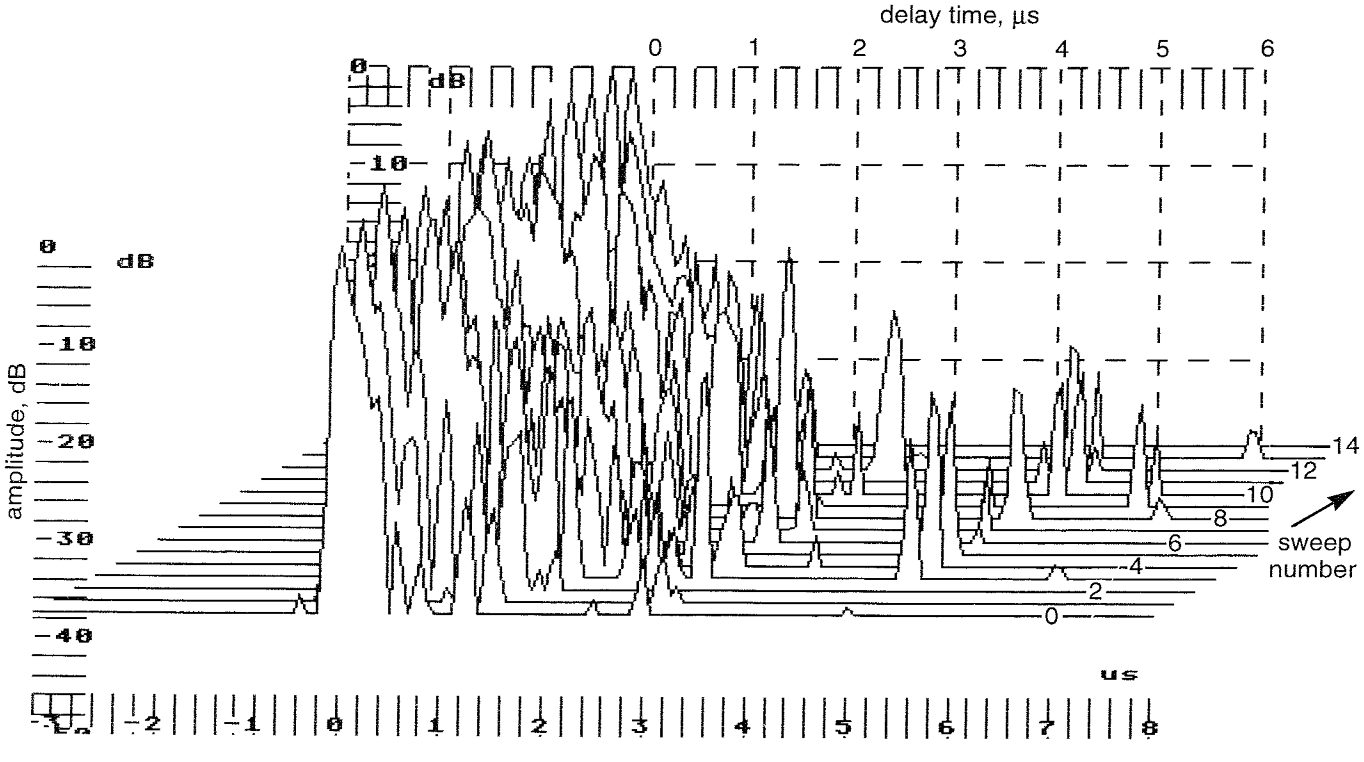

Fig. A.2 - Multipath delay profiles (Sports Hall).

Published by BBC RESEARCH AND DEVELOPMENT DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP